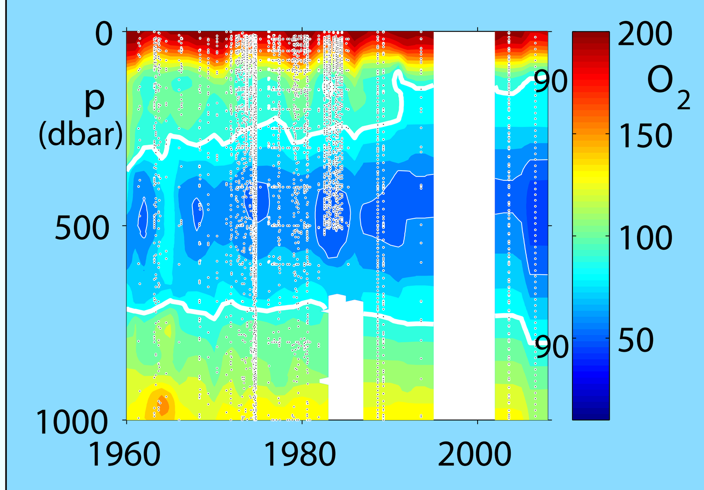
Changes in the Ventilation of the Oxygen Minimum Zone of the Tropical North Atlantic

(1) (2)

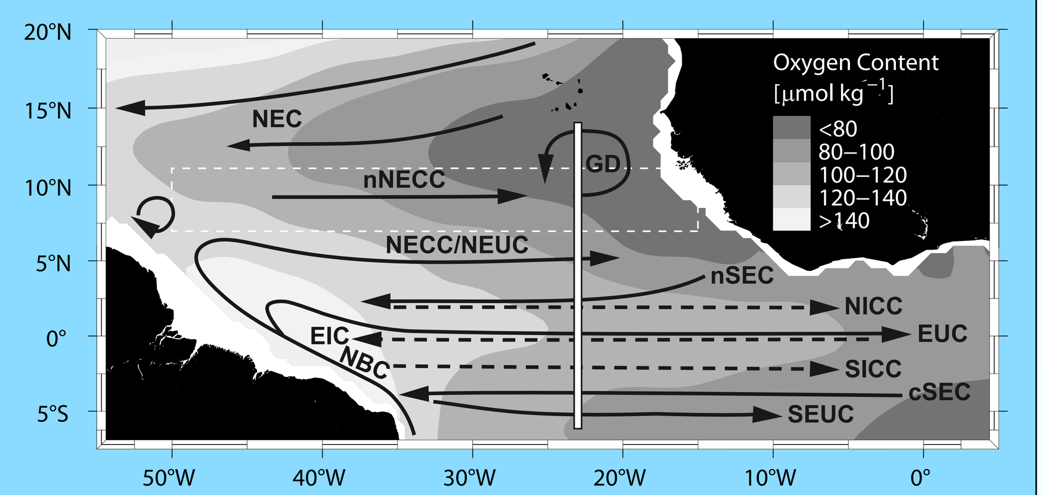
Peter Brandt[1], Verena Hormann[1], Arne Körtzinger[1], Martin Visbeck[1]
Gerd Krahmann[1], Lothar Stramma[1], Rick Lumpkin[2], Claudia Schmid[2]

Introduction

Oxygen minimum zones (OMZs) are caused by a combination of weak ventilation and elevated oxygen consumption due to enhanced respiration. Stramma et al. [2008] reported an expansion of OMZs in the World Ocean, with strongest oxygen depletion in the tropical North Atlantic OMZ.



Dissolved oxygen concentration [μmol/kg] versus time and pressure in the eastern tropical North Atlantic (10° to 14°N, 20° to 30°W). [Stramma et al., 2008]

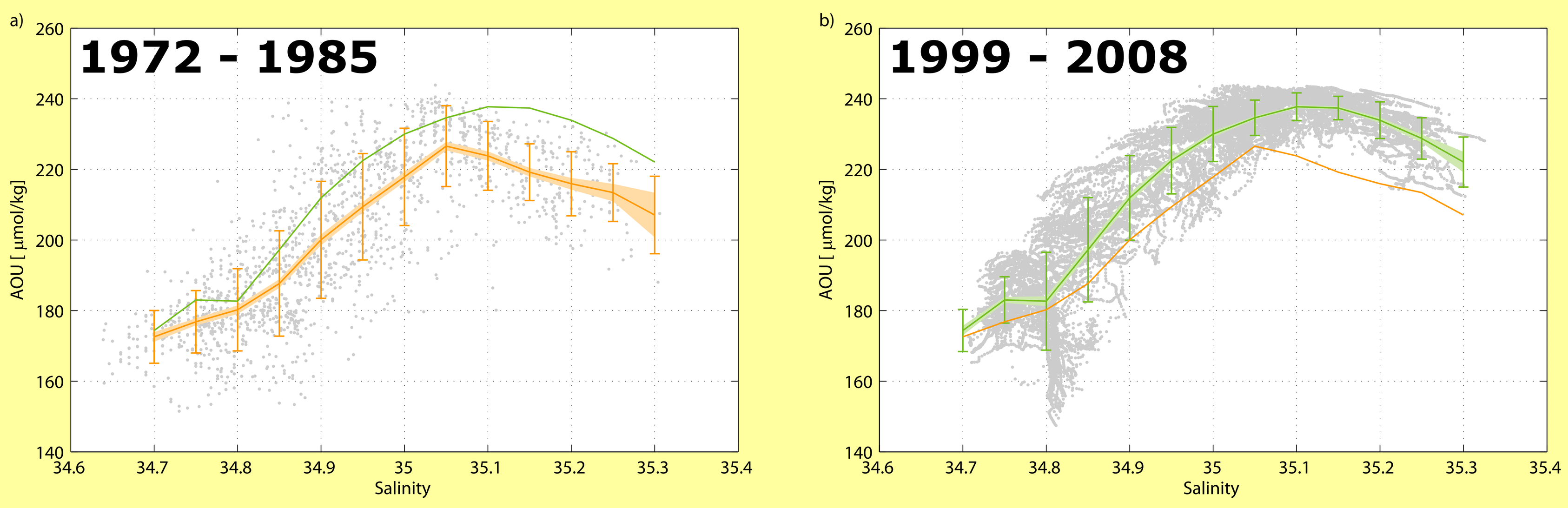


Surface (black solid) and intermediate (black dashed) circulation and oxygen concentration [μmol/kg] at 300-500 m. The conceptual model is applied to the region marked by the white dashed rectangle.

Summary

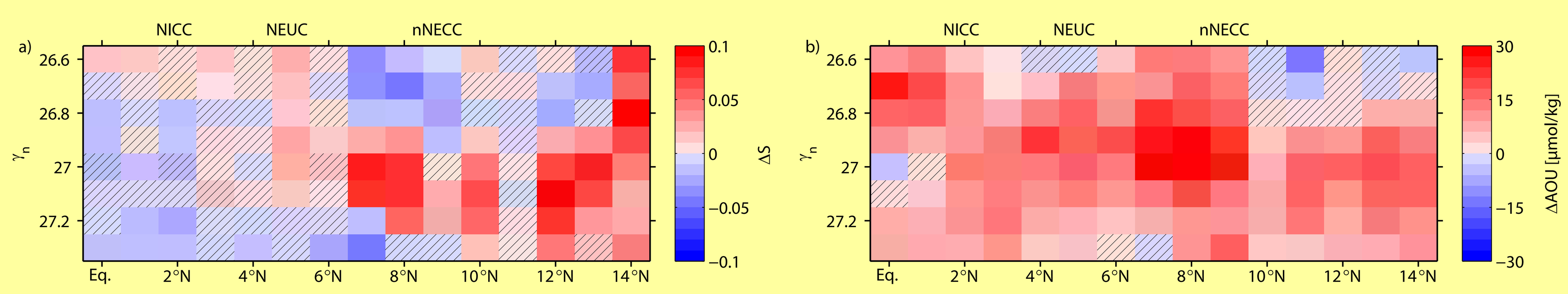
Changes in the ventilation of the OMZ of the tropical North Atlantic are studied using cruise data (1999-2008) and historical data (1972-1985). In the core of the OMZ at about 400 m depth, a highly significant oxygen decrease of about 15 μmol/kg is found between the two periods. The scatter in the local oxygen-salinity relationships decreased from the period 1972-1985 to the period 1999-2008, suggesting a reduced filamentation due to mesoscale eddies and/or zonal jets acting on the background gradients. Here we suggest that latitudinally alternating zonal jets with observed amplitudes of a few centimeters per second in the depth range of the OMZ contribute to the ventilation of the OMZ. Using a conceptual model of the ventilation of the OMZ, it is suggested that a weakening of zonal jets, which is in general agreement with observed hydrographic evidences in the tropical North Atlantic OMZ, is associated with a reduction of the mean oxygen levels in the OMZ.

Oxygen Depletion and Salinity Changes along 23°W



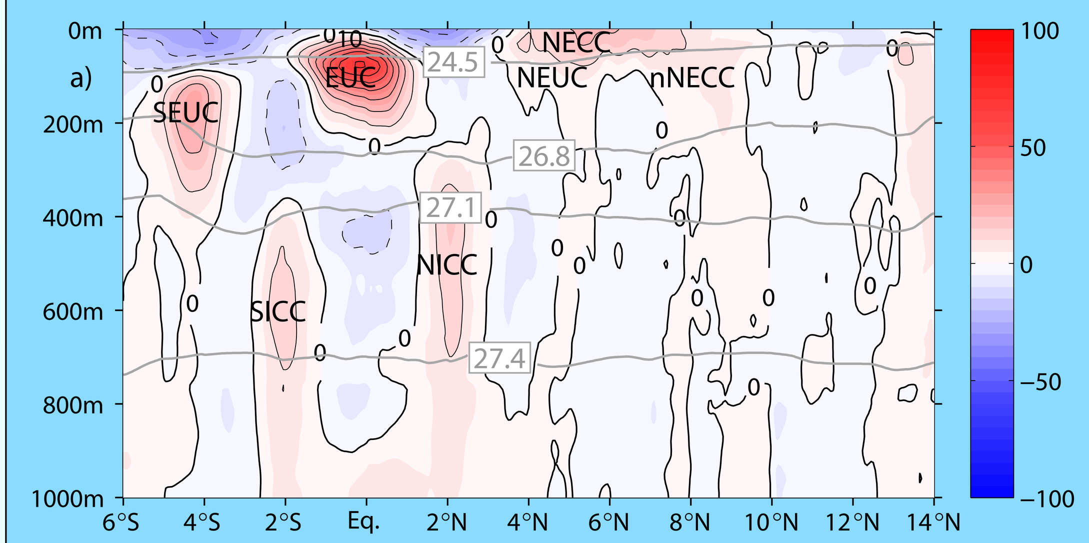
Apparent oxygen utilization (AOU) [μmol/kg] on the neutral density surface γ_n = 27.1 ± 0.05 as function of salinity for the two periods (a) 1972-1985 and (b) 1999-2008 (gray dots). Bin-averaged AOU concentration, with standard deviation (bars) and standard error (shaded), is given by orange (1972-1985) and green (1999-2008) curves.

The comparison of hydrographic properties for the periods 1972-1985 and 1999-2008 revealed (i) a decrease of the oxygen concentration (increase in AOU) in the core of the OMZ of the tropical North Atlantic of about 15 μmol/kg and an increase of salinity at the oxygen minimum of about 0.1; and (ii) a decrease of the oxygen concentration for density levels γ_n = 26.6-27.3 within the eastward jet at about 9°N, while the salinity decreased/increased above/below γ_n = 26.9, respectively.



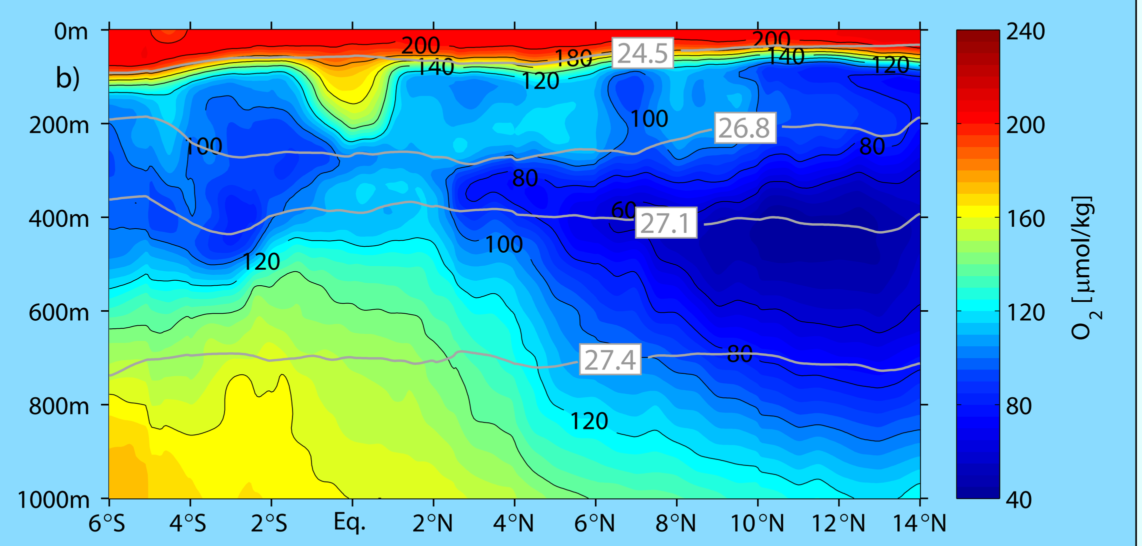
Differences in (a) salinity and (b) AOU [μmol/kg] for the period 1999-2008 minus 1972-1985 as function of neutral density and latitude. Absolute differences that are smaller than their standard error are hatched.

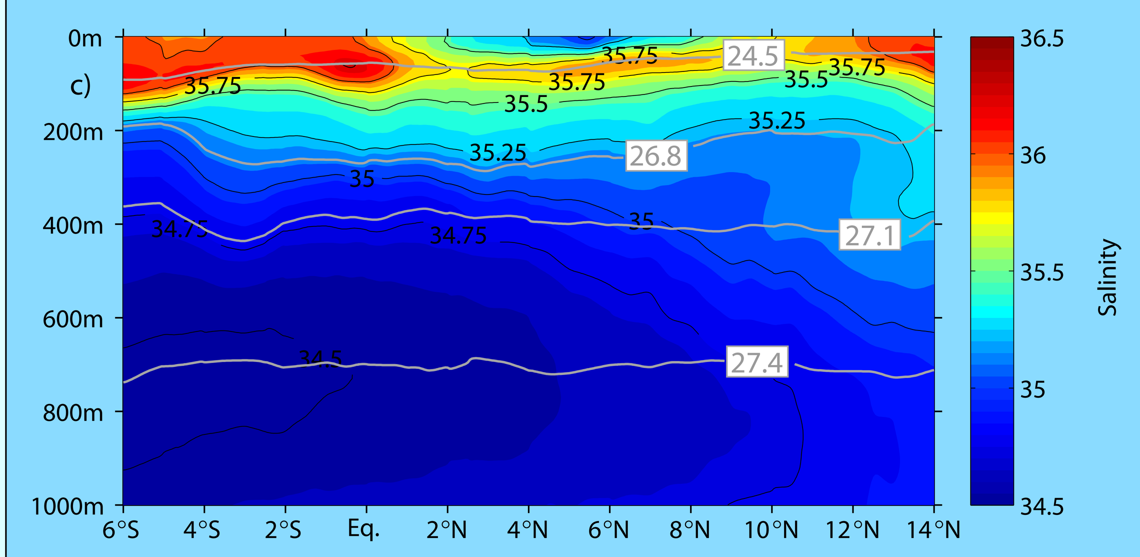
Circulation and Hydrography along 23°W



The mean circulation in the central tropical Atlantic is characterized by narrow east- and westward current bands (or jets). Note in particular, latitudinally alternating zonal flow in the area of the OMZ.

At the neutral density surface γ_n = 27.1, which corresponds to the core of the OMZ, highest oxygen content is found in the equatorial region. Eastward current bands are generally associated with elevated oxygen content.





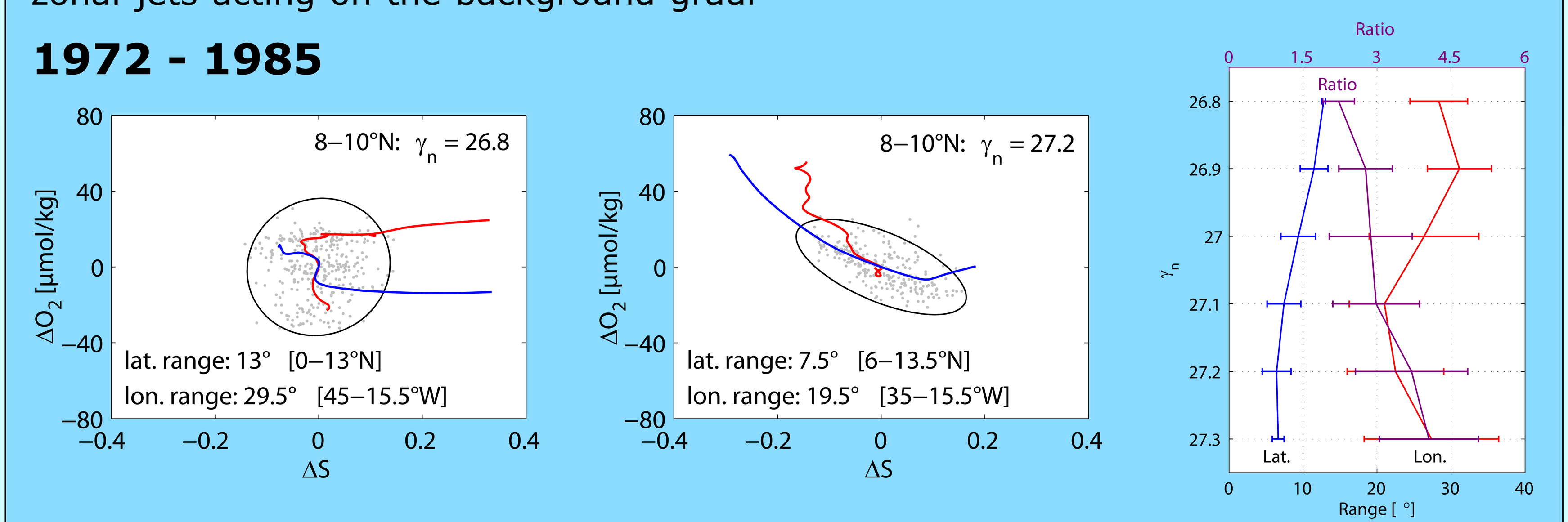
The salinity distribution is characterized by a subsurface maximum defining the Subtropical Underwater, a decrease with depth in the central water layer, and a minimum at about 800 m representing the core depth of Antarctic Intermediate Water.

Mean gridded (a) zonal velocity [cm/s], (b) oxygen content [μmol/kg], and (c) salinity from 18 research cruises carried out between 28.5°W and 23°W during 1999-2008.

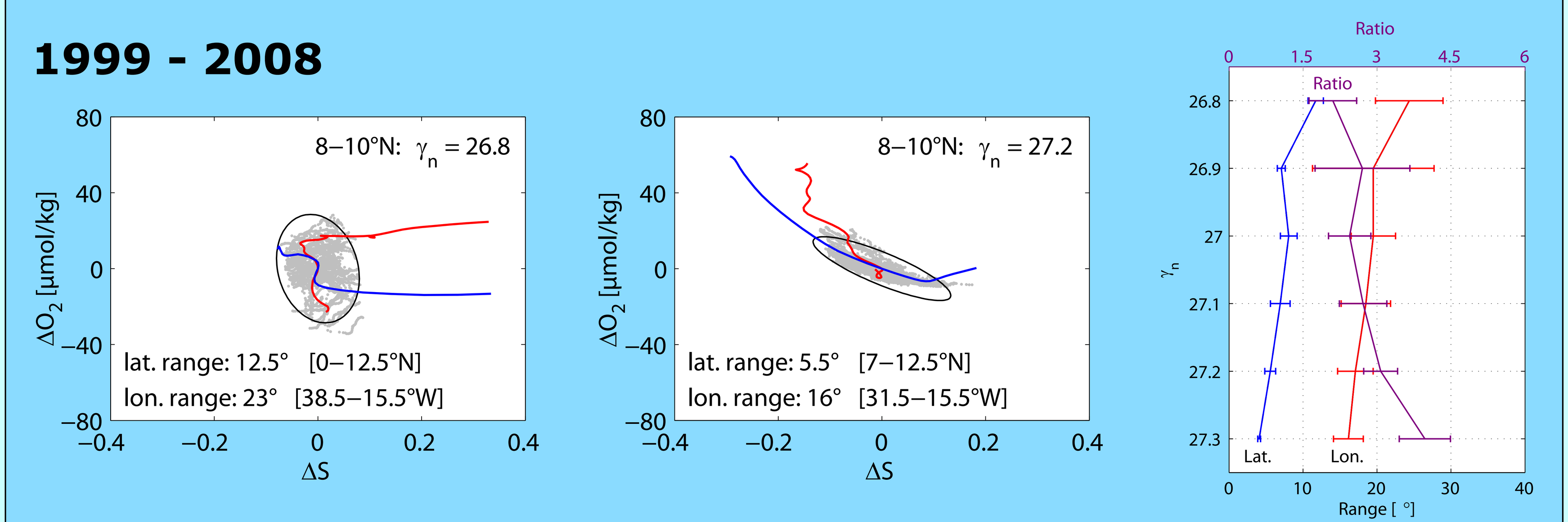
Scatter in the Local Oxygen-Salinity Relation

The scatter in the local oxygen-salinity relations decreased from the period 1972-1985 to the later period, suggesting a reduced filamentation due to mesoscale eddies and/or zonal jets acting on the background gradients. The ratio between squared latitude and longitude ranges is proportional to the ratio between meridional and zonal eddy diffusivities.

1972 - 1985



1999 - 2008



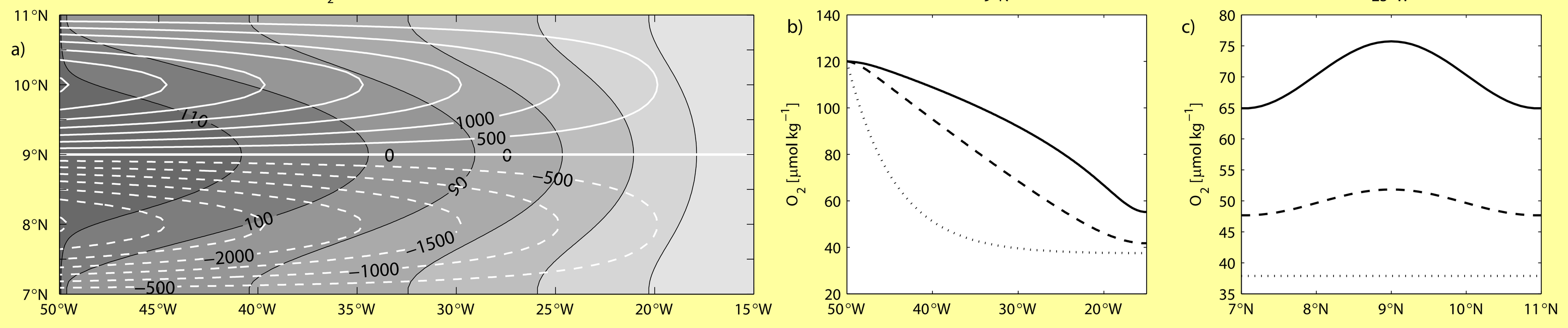
Oxygen-salinity anomalies (ΔO_2-ΔS) between 22°-24°W relative to box means for the period 1972-1985 (top) and 1999-2008 (bottom) with corresponding variance ellipses. Blue and red curves mark the WOCE Global Hydrographic Climatology (WGHC) ΔO_2-ΔS relation along meridional (23°W, 0°-15°N) and zonal (50°-10°W, 9°N) sections, respectively. Latitude and longitude ranges are defined by the intersection of the WGHC curves with the variance ellipses.

Conceptual Model of the Ventilation of the OMZ

The model is only representative for a single eastward jet and its westward return flow that is superimposed on the background meridional curvature of the oxygen distribution at a given density surface. In the model, the oxygen tendency on the left-hand side is attributed to the following 7 terms on the right-hand side: 1) oxygen consumption, 2) zonal advection, 3) meridional advection, 4) zonal eddy diffusivity, 5) meridional eddy diffusivity associated with east- and westward jets, 6) meridional eddy diffusivity associated with the large scale oxygen distribution between the equatorial region and the northern subtropics, and 7) vertical diffusivity.

$$\frac{\partial C}{\partial t} = -JC - u\frac{\partial C}{\partial x} - v\frac{\partial C}{\partial y} + K_x\frac{\partial^2 C}{\partial x^2} + K_y\frac{\partial^2 C}{\partial y^2} + K_y F_{corr}\frac{\partial^2 C_{bg}}{\partial y^2} + K_z F_{corr}\frac{\partial^2 C_{bg}}{\partial z^2}$$

The model simulates increased oxygen levels within the eastward jet as well as increasing mean oxygen levels at the eastern boundary with increasing jet strength.



(a) Simulated oxygen distribution [μmol/kg] and streamfunction [m²/s] at γ_n = 27.1 for u_0 = 5 cm/s, k_x = 500 m²/s, and k_y = 200 m²/s. (b) Zonal and (c) meridional oxygen distribution [μmol/kg] as simulated with u_0 = 5 (solid), 2.5 (dashed), and 0 (dotted) [cm/s].

References

Stramma, L., G. C. Johnson, J. Sprintall, and V. Mohrholz, 2008: Expanding oxygen-minimum zones in the tropical oceans. *Science*, 320, 655-658, doi:10.1126/science.1153847.

Acknowledgement

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